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Land Use Change And Forestry Climate Project Regional Baselines: A Review

Jayant A. Sathaye* And Kenneth Andrasko[#]

*Lawrence Berkeley National Laboratory, Berkeley, CA 94720
[#]U.S. Environmental Protection Agency
Office of Atmospheric Programs/CCD Washington DC

(Corresponding authors: * Tel.: +1-510-486-6294; Fax: +1-510-486-6996; JASathaye@lbl.gov. or [#] Tel.: +1-202-343-9281, Fax: +1-202-343-2202. andrasko.ken@epa.gov)

Abstract. Climate change programs have largely used the project-specific approach for estimating baseline emissions of climate mitigation projects. This approach is subjective, lacks transparency, can generate inconsistent baselines for similar projects, and is likely to have high transaction costs. The use of regional baselines, which partially addresses these issues, has been reported in the literature on forestry and agriculture projects, and in greenhouse gas (GHG) mitigation program guidance for them (e.g., WRI/WBCSD GHG Project Protocol, USDOE's 1605(b) registry, UNFCCC's Clean Development Mechanism). This paper provides an assessment of project-specific and regional baselines approaches for key baseline tasks, using project and program examples. The regional experience to date is then synthesized into generic steps that are referred to as Stratified Regional Baselines (SRB). Regional approaches generally, and SRB in particular explicitly acknowledge the heterogeneity of carbon density, land use change, and other key baseline driver variables across a landscape. SRB focuses on providing guidance on how to stratify lands into parcels with relatively homogeneous characteristics to estimate conservative baselines within a GHG assessment boundary, by applying systematic methods to determine the boundary and time period for input data.

Keywords. GHG mitigation, project-specific, carbon sequestration, stratified regional baselines,

1. Introduction

Climate change mitigation projects to reduce greenhouse gas (GHG) emissions are being implemented in land-use, energy, landfill gas, and other sectors. A mitigation project may be defined as a planned set of activities that are bounded by specific geographic and temporal boundaries and an identifiable set of institutional arrangements (Brown et al., 2000) that generate potentially tradable GHG emissions offsets. This paper provides a comparison of two major alternative methods (project-specific and regional baselines) being used to develop baselines for land-use change and forestry projects, and outlines a synthesized version of the latter termed Stratified Regional Baselines (SRB) approach.

The estimation of emissions reductions of a mitigation project entails the following overarching steps (Vine, Sathaye, and Makundi 2001): (1) setting the project boundary and monitoring domain, (2) selecting the without-project baseline activities and estimating GHG emissions, (3) estimating the project case emissions, and (4) calculating the emissions reduction with respect to the baseline. A monitoring domain may or may not be the same as a project's physical boundary. The methodology for setting baselines for forestation projects may differ from that for projects that avoid deforestation or utilize other land use management practices.

Mitigation projects are being advanced and considered under various state, national and international schemes that have proposed their own methods or guidelines for developing baselines. In the U.S., for example, the U.S. Department of Energy revised its reporting guidelines for the Voluntary Greenhouse Gas Reporting Program (known as 1605(b)) in an effort to improve its capacity to estimate reduced or avoided GHG emissions (U.S. DOE 2006). The Chicago Climate Exchange (CCX) Forestry Offset Projects fall under three categories: forestation and forest enrichment, combined forestation and forest conservation, and urban tree planting. Forestation and forest enrichment projects, including urban tree planting, initiated on or after January 1, 1990, on unforested or degraded forest land can earn CCX offsets at a rate based on the annual increase in the carbon stocks of above-ground, living biomass during the CCX program years (2003-2010). The baseline is generally the average annual emissions or uptake during 1998-2001 (see http://www.chicagoclimateex.com).

Internationally, the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) developed the *Greenhouse Gas Protocol for Project Accounting* for estimating project-level GHG savings (WRI/WBCSD, 2005) that offers a choice of two baseline procedures. The project-specific procedure identifies a baseline scenario specific to a given project activity, and is valid only for that project. The second is the performance standard procedure, which reviews all baseline candidate activities and then analytically selects a GHG emission rate[1] to set as a benchmark against which to evaluate proposed projects.

The WRI/WBCSD steps call for (1) defining the GHG assessment boundary, including associated secondary effects and leakage, (2) selecting a baseline procedure (project-specific or performance standard). (3) identifying baseline candidates by defining products, geographic area, and temporal range, and (4) estimating baseline emissions and selecting the most likely baseline using either of the two approaches.

The international landscape is dominated by programs generating or certifying emissions reduction activities directly under the Kyoto Protocol or indirectly in support of it. These include the Clean Development Mechanism (CDM) for emissions reduction projects in developing countries, the Dutch government's Certified Emission Reduction Unit Procurement Tender, the World Bank’s Prototype Carbon Fund and BioCarbon Fund among others, and other carbon trading programs have developed methodologies and guidelines for calculating avoided greenhouse gas emissions and enhanced removals from mitigation projects.

Prior to 2005-06, there has been little consistency in the treatment of (1) the definition of mitigation categories, (2) carbon pools to be included in a program (although the five identified in the IPCC Good Practices Guidance (20006) are becoming standard), and (3) approaches for estimating baseline emissions across programs. Administrative bodies responsible for the aforementioned programs are rapidly exploring ways to bring greater rigor and uniformity, including adapting other programs’ methods.

The clean development mechanism (CDM)[2], for example, limits the accounting of carbon pools for certain types of forestation projects to those within a project boundary and stipulates three different ways that project-specific baseline scenarios may be set: (1) Existing or historical, as applicable, changes in carbon stocks in the carbon pools within the project boundary, (2) Changes in carbon stocks in the carbon pools within the project boundary from a land use that represents an economically attractive course of action, taking into account barriers to investment, and (3) Changes in carbon stocks in the pools within the project boundary from the most likely land use at the time the project starts.

Issues that make the setting of baselines challenging include land eligibility, additionality, leakage, and permanence as issues that would change estimates of emissions reductions (Brown et al. 2000). Eligibility refers to existing rules, regulations, laws, etc. that require that lands or land use in a proposed project be managed or implemented in a manner specified by a GHG mitigation program. Additionality essentially refers to a project developer's or landowner's intent to undertake a project. Might the developer or owner have undertaken the project or its land use activities for some other reason anyway? The economics literature refers to this issue as a free-rider problem, which arises routinely in cases which require the allocation of responsibility and ownership of a public good or bad. Leakage refers to the possibility that net emissions reductions of a project may be lower (or higher) because of increased (decreased) emissions elsewhere that are attributable to the project. Finally, permanence or reversibility refers to whether the net emissions reductions attributable to the project may be reversed in the future due to natural or manmade causes, or convergence of the actual baseline with the project case emissions. In either case, net emissions reductions may need to be adjusted either now or in the future to account for the impact of these factors, depending on GHG mitigation program rules or market preferences.

2. Estimating carbon emissions reduction: Evolution of approaches

Approaches to the estimation of baselines in mitigation projects have evolved over the last decade. The earlier approach was project-specific and focused solely on the changes in land use and carbon density within the project area (see Section 3 for further discussion of the experience with this approach). Subsequent approaches recognized that land use change rates may depend on socioeconomic and other drivers that may be used to set rates for a much larger area. The same variables and relationship to land use change could be used to set baselines for other projects within this area. This led to the formulation of regional baselines that apply to a broader area around a project (see Section 4 for further discussion of the experience with this approach)[3]. Each approach began with the use of simple methods that became more complex over time in order to account for the heterogeneity of the lands and their carbon pools and densities, and the factors that drove land use change. The increased complexity permitted the use of more disaggregated data and the ability to sift through many driver variables.

The project-specific approach has been used to estimate baseline emissions for the project as a whole, based on trend extrapolation of historical data and logical arguments for each of the many heterogeneous activities within a project boundary.

While the project-specific approach for estimating baselines works well for large contiguous projects, it can be burdensome for a collection of heterogeneous small projects that span larger areas. Tipper and De Jong (1998) for instance developed regional baselines using satellite imagery to determine the deforestation rates for Chiapas, Mexico. This early application used simple trend extrapolation to determine the future deforestation rate for the entire area. Subsequent analysis led to the formulation of a more complex approach that related deforestation rates to two variables, distance from roads and farms. Two papers in this journal special issue, Brown et al. and Boer et al., describe several similar but more complex approaches to the formulation of regional baselines. Results of their approaches are discussed in Section 4.

Table 1 below summarizes the key characteristics of the project and regional approaches. The project-specific approach is being used by existing programs (e.g., Prototype Carbon Fund; Climate Trust GHG mitigation program in Oregon, US; and the CDM), and has been used by past programs (like the UNFCCC Activities Implemented Jointly pilot program), to develop baselines. A simplified version of the regional baselines concept has been adopted in part by the US DOE 1605(b) GHG registry program revised guidelines (DOE, 2006) for reporting forestry and cropland management projects. This guidance uses a base year or period rather than a dynamic baseline projected into the future. It provides default tables and Web-based decision support tools at the county scale (the smallest U.S. administrative unit above a town) that customize permanent forest inventory plot data on growth and C stocks by forest type in the Carbon OnLine Calculator (COLE), or soil carbon change data by cropland tillage practices in the COMET-VCR tool (DOE, 2006).

The project-specific approach generally cannot assure the same baseline scenario or GHG emissions estimate for identical projects over similar stratified areas within a given region. Consistent, transparent use of an accepted Afforestation-Reforestation (AR) methodology in the CDM context may encourage convergence of project baselines, although there currently are too few accepted projects and methodologies to test this premise.

One critique of the project-specific approach is that it may incur higher transaction costs for baseline estimation, since each project would need to be estimated separately (e.g., Antinori et al, 2006). For example, the cost estimate of Sudha, Shubhashree, et al. (this issue) for setting a regional baseline for the Kolar district, southern India, is one-quarter the cost of the project-specific method for a fraction of the same area (Ravindranath, Murthy, Sudha, et al., this issue). The regional approach may have a high first cost, but low or negligible cost when amortized over multiple projects within a region.

The project-specific approach applies to a project area within a specific geographic boundary. For diverse projects with many carbon pools and soil and biomass characteristics, baselines that are stratified by land area characteristics are desirable. The regional approach calls for a larger spatial zone that may extend well beyond a single project boundary, necessitating stratification by some set of variables that allow non-continuous parcels with similar characteristics to have the same baseline value. Regional baselines are most useful and cost-effective where multiple projects are proposed by developers (e.g., Mississippi Alluvial Valley in the U.S., where six to a dozen forest restoration projects are being implemented (see http://climate.wri.org/sequestration.cfm), or where government or private entities provide incentives to target mitigation activity due to other public interests (e.g., poverty eradication and biodiversity conservation).

TABLE 1

Key characteristics of two general approaches for setting baselines

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3. Project-Specific Baselines Experience

Numerous projects have used what has become known as the project-specific approach for setting a baseline (Table 2). Following WRI/WBCSD, the steps in this approach would include: (1) select a GHG assessment boundary, (2) identify baseline candidates within the project area and over a temporal period, (3) identify barriers to the baseline scenario, and (4) select the most likely baseline candidate. Often, the viability of each baseline candidate is compared with respect to barriers that inhibit its implementation. As we discuss below, earlier approaches used logical arguments to select a baseline scenario but most did not explicitly identify barriers and evaluate alternative candidate scenarios. The methodology and data are specific to each project, which may include the use of satellite images, transition matrices, and/or simple extrapolation of historical trends (Table 2).

For projecting baselines the methods ranged from simple logical arguments to complex analytics, both of which may make use of extensive data gathered from satellite images, forest inventories, or other sources. The Noel Kempff project, for instance, initially used simple logical arguments based on a quantification of baseline carbon in proxy areas (Table 2, and Brown et al, 2000). Similarly, the Costa Rican Protected Areas Project used a simple extrapolation of historical deforestation rates to project a future baseline of deforestation in a selected area (Busch et al,.1999).

The CDM experience includes 20 baseline methodologies proposed, and three approved (the China, Moldova, and Albania projects). The Moldova methodology[4] has two baseline estimates, of which the higher one should be used. a) historical practice by the project proponent, and b) regional or national background reforestation rates applied to all lands technically available for afforestation, to give a percentage of the project areas that would have been reforested in the baseline. The latter is like a regional baseline, since the project consists of more than 200 parcels of afforestation spread over a large portion of the country.

One lesson being learned from the CDM methodologies and the papers in this journal issue (e.g., (Ravindranath, Murthy, Sudha, et al., this issue), is the interplay of eligibility conditions and baseline scenario selection. If the eligibility conditions for the baseline are chosen to be narrow (i.e., including only degraded lands not attractive for reforestation), then the baseline development can be simplified.

Conceptual analyses of projects have explored numerous techniques. The Upper Magat Watershed in the Philippines (Lasco et al., this issue) used a simple extrapolation of historical 10-year trend of changes in land use. Similarly, for the Kolar project in India (Ravindranath, Murthy, Sudha, et al., this issue), the authors collected data on forestation rates for the past 10 years and extrapolated the land use change patterns using the historical time trend over this period. Project developers collected extensive historical data on land use change and carbon density, but the approaches used for projecting future changes in these parameters were relatively much simpler.

The Lower Yazoo River Basin (LYRB) hypothetical project analysis in the Mississippi River Valley, south-central U.S. (Sommer et al., 2004, described further below), analyzed potential for afforestation of frequently flooded marginal croplands converted from bottomland hardwood forests in the past. Using national land use data for the four counties analyzed, the analysts estimated past afforestation rates, and assumed that 787 hectares (ha) of marginal land on the project site of 5,427 ha would be planted immediately, and the resulting plantation would yield carbon benefits over a 60-year rotation period (Sommer et al., 2004).

An advantage of modeled baselines versus a time trend extrapolation is that the former can capture periodic fluctuations in biomass growth or variation in vintages of stands over a landscape, which the latter approach may not. For instance, the analysis of historical carbon storage in the Chiapas project shows that using data on the 1984, 1990, and 1996 carbon stocks, the authors chose a simple extrapolation of the three different rates of stock change and picked the middle one as the baseline (Tipper and de Jong, 1998). A modeled analysis of the reasons for the variation in deforestation rates might have revealed a periodicity which is not evident in the simple extrapolation.

Important temporal baseline issues include the time period for which a baseline is held to be valid. Early projects assumed the baseline was fixed for the duration of the project. A baseline may be adjusted after the project has been in place for some years, if a GHG program dictates the validity period and the conditions that trigger review or revision of baseline driver variable assumptions. The CDM allows projects to be established for 30 years, or for 20 years and then renewed twice for an additional 20 years. Adjustable baselines may be preferred from a GHG program's perspective in order to permit more accurate accounting of a project's carbon benefits over its life, but they may pose too high a risk for project developers, so few projects are implemented.

In Table 2, several of the projects planned to use adjustable baselines to reflect changes in timber markets, forest laws, rates of deforestation, availability of new satellite data, etc. A recent review of the Noel Kempff project by its developers, The Nature Conservancy, suggests that the new baseline yields lower carbon benefits than the one developed at the start of the project; and certification of the project's carbon benefits by the firm SGS in late 2005 resulted in even lower estimates. Similarly, the monitored carbon benefit from the Reduced Impact Logging (RIL) project was reportedly lower than estimated at the initiation of the project in the 1990s (Pinnard and Putz, 1997; and UNFCCC AIJ database, at http://unfccc.int). Or, carbon benefits could be higher for other projects where deforestation rates have increased. The experience with these cases argues for an adjustable baseline.

TABLE 2:

Project-specific baseline methods used by selected climate change projects, over time

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4. Emergence of Regional Baselines to Address Project-Specific Issues

Several obstacles to use of the project-specific method emerged. Current application of the project-specific approach generally calls for the evaluation of barriers that could inhibit alternative candidate baseline scenarios (e.g., as used in the project protocols in WRI/WBCSD, 2003). This process of listing barriers and evaluating their potential for inhibiting a project tends to be time consuming, inherently open to bias, may not be transparent, and raises questions about the confidentiality of data sources (Table 1).[5]

The likely higher transaction costs of establishing project specific baselines are likely to reduce the number of forestry projects in a region that attract investment flows, and smaller projects are likely to be particularly affected by these costs.[6] These factors can lead to inconsistent baseline emissions for similar projects within the same spatial zone, and exacerbate other barriers to AR project implementation like the short planning period for carbon credits (typically a few years or until 2012 for CDM projects), and the lack of up-front financing.

The emergence of regional baselines in the land-use change and forestry (LUCF) sector addresses many of the concerns about project-specific baselines. Earlier work on the setting of regional baselines for the Chiapas region in Mexico is reported by Tipper and de Jong (1998) (Table 3). They estimate historical land use change data that shows a decline in carbon stock from 63.6 Mt C in 1974 to 44.6 Mt C in 1996 but with the rate varying between 0.4% a year to 2.3% a year over this period. In their approach, they suggest using an average rate of 1.6% per year to smooth out the fluctuations over this historical period and use it to project future deforestation to 2045, while noting that such a trend-based approach ignores important changes in economic structures, technology, and/or political developments. In a subsequent modification of this approach, de Jong (2002) developed a process-based model that relates deforestation to farmer density and distance to agricultural land as the two key driver variables. This permits the use of a single expression for estimating deforestation rates in Chiapas that are site specific. They note that a problem with setting project-specific baselines in developing countries is the application of regional land use change data on deforestation to a particular site without taking geographical context and changes over historical time periods into account.

De Jong (2002) compares the resulting baseline emissions estimates from the use of the project-specific approach reported in Table 2, with the aforementioned time-trend baseline and a site-specific multiproject baseline for all of Chiapas (Figure 1). The time-trend regional baseline yields the highest emissions estimates while the project-specific case yields the lowest values. The former is high because the project site has much lower deforestation rate than the average, and the project-specific projection is low because it is an historical extrapolation that ignores the distance to the agricultural land or community.

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Figure 1 Accumulated baseline emission estimations for Juznajab la Laguna, Chiapas, Mexico

The result for Chiapas is a combination of project-specific approach for individual Plan Vivo (landowner maps of current and proposed GHG project land use), overlaid by a regional baselines analysis that provides carbon change values for the project land parcels. This overlaying of a larger region for baseline analysis over the project lands is variously called the study area (de Jong, 2000), the monitoring domain (MacDicken, 1997), the mitigation activity domain (Andrasko, 1997), and recently the GHG assessment boundary (WRI/WBCSD, 2005), which includes upstream or downstream industrial or other activities. In this paper, we use the term GHG assessment boundary or simply the "assessment boundary" while acknowledging that most forestry projects do not estimate upstream and downstream GHG impacts and the term as used here refers to a larger analytic region beyond the project boundary. (e.g., in most of the examples in Table 3).

The assessment boundary, and the analytic method chosen for setting a baseline, have a major impact on the quantitative baseline estimate. Brown et al. (this issue) report on making projections of initial forest cover levels and deforestation rates, for six avoided deforestation projects in Belize, Bolivia (Noel Kempff in northeast Bolivia), Brazil and three separate sites in Mexico. They compare the consistent use of three methods – Forest Area Change (FAC), the Land-use Carbon Sequestration (LUCS), and the Geographical Modeling (GEOMOD) models--for setting baselines.

FAC is the simplest approach and uses population rate of change as the single driver to project changes in forest cover over large sub-national or national land areas. The LUCS and GEOMOD methods may be applied to both smaller (project) scale lands and more broadly at the regional level. The latter approach also provides the spatial distribution of forest cover change within a region. A unique feature of the approach is that it provides the probability of an area being deforested as compared to its happening by chance. Each approach relies on historical data on land use change either over a broad area as in the case of the FAC approach or at a smaller scale in the latter two approaches. The data requirement is thus quite small for the FAC approach but can be much more complex and expensive with the GEOMOD approach, and in-between for the LUCS approach.

The FAC approach produces only regional baselines since it is suited for analysis at the sub-national or national levels and not at the project level. The latter two approaches may be used either at the project scale or a broader regional scale. Brown et al. (this issue) compare the use of each approach for the development of regional baselines around six project locations.

For the Noel Kempff project, they compare the use of GEOMOD project-specific values vs. regional values derived from the FAC and LUCS models. They report that the FAC approach projects baseline carbon emissions of 11.54 Tg C, the LUCS approach results in 0.18 Tg C and the GEOMOD approach in 1.05 Tg of C emissions, all over 20 years—baselines equal to only 1.6% (LUCS) and 8.7% (GEOMOD) of the state-level estimate by FAC. The GEOMOD approach thus yields an estimate that is an order of magnitude larger than the LUCS approach, but an order of magnitude lower than the FAC estimate. The GEOMOD approach being project-specific tracks the changes in carbon stock annually, and shows substantial year to year variation in t C/ha that the other two approaches are not able to represent.

Figure 2 illustrates the importance of the relationship between the project and two larger GHG assessment regions roughly 57 times (case A, the entire Santa Cruz state) and five (case B, state sub-region surrounding the project) times the Noel Kempff project area. The state-level FAC model (driven by population-change) estimates the baseline initial condition as 55% forest cover (over a landscape with more croplands than the project region), while Case B using LUCS (driven by demand for agricultural land), and GEOMOD (using a half-dozen explanatory variables of deforestation trends) both set the baseline forest cover much higher, at 85%.

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Figure 2: Role of GHG assessment region selection decision on baseline estimation: Example of Noel Kempff project, Bolivia (Brown et al., this issue).

The case study for Jambi is conceptually and analytically similar to the GEOMOD analysis. It specifies a logistic cumulative distribution function to define the probability of a land area being converted to another land use using driver variables, such as proximity to a transportation channel, area of agricultural land, job opportunities, population density, income, etc. It uses data from 1986 and 1992 LANDSAT TM images to map changes in land cover/use and the consequent changes in carbon emissions. Using mostly data at the district level it projects a baseline for a proposed project area within the district.

TABLE 3:

Regional baseline methods for selected projects

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Sommer et al. (2004) analyze the mitigation option to afforest marginal agricultural land that is subject to flooding in the LYRB area in Mississippi. Since the area is bounded by flood levees, the physical infrastructure sets the spatial zone for a homogenous ecological area. Carbon density data are collected from sample inventory plots for the United States.[7] While the spatial zone is well defined, the temporal period is not investigated for inflexion points that might have altered the time trend of annually forested area. Sommer et al. (2004) compare the application of the two major baseline approaches. The project-specific approach yields higher carbon benefits than the performance standard procedure[8], since financial analysis suggests that no afforestation would occur on the portion of project land that is suitable for this purpose.

Several recent CDM developments mimic the effect of the regional baseline approach, including the Moldova project regional/national afforestation baseline noted above. Decision CMP.1 by the UNFCCC COP/MOP1 in Montreal in 2005 on the CDM[9] allows a set of projects of the same mitigation activity within a country or region to be bundled as a single CDM project, to reduce CDM-related transaction costs (like baseline estimation). The decision also allows for a program of activities achieved by private or government initiative to be considered for the CDM, also know as sectoral CDM (Figueres, 2006a and b), which potentially could evolve into methods more like those for regional approaches.

Three India hypothetical project case studies by Sudha, Ramprasad, et al. (in Table 3), and Hooda et al., and Ravindranath, Murthy, Sudha, et al. (both in this special issue) use a somewhat different approach. India passed a forest conservation law in 1980, and deforestation activities in the three Indian study areas are negligible, so these studies focus on forestation schemes on waste (degraded) and fallow lands. They rely on historical data for the rate of land use change from such lands to afforested lands, on Indian Forest Department forestation activity data on lands defined as "forest," a household survey for historical afforestation rates on private farms, and on measurements of biomass and soil carbon on a stratified sample of relevant lands. The remaining degraded land in forests and on farms forms the basis for estimation of the future potential. The rate of forestation is extrapolated using a time trend based on historical data.

4.1 Summary classification of methods by mitigation option

Based on experience to date estimating regional baselines, Table 4 shows a summary classification for three mitigation options-- avoided deforestation, forestation, and forest management-- where similar data and methods may be used to estimate land use change and carbon stock change rates for setting an emissions rate.

TABLE 4:

Classification of regional baseline methods, by land use, for estimating land use change and carbon stock change

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<u>Avoided deforestation</u> can occur in relatively undisturbed or in disturbed forests. Biomass carbon stock estimates may be available from forest inventory or other plot measurement data, or estimated by Holdridge-type forest classification, and soil carbon may be available in inventory data or estimated using spatial covariation with respect to soil texture and drainage (Davidson 1995). The estimation of carbon density requires measurements of samples that are regionally stratified uniquely for each carbon pool (de Jong, 2002). Estimating the rate of deforestation land use change in the baseline generally uses remote sensing imagery from at least two dates, and often a model that relates it to predisposing and driver variables, such as elevation and distance from roads or existing deforestation, to estimate the location of future deforestation (Brown et al. and Boer et al., this issue).

Both the carbon stock change and the rate of land use change would be stratified within the GHG assessment boundary. Stratification would permit the use of multiple values--one for each area stratified to represent the same set of characteristics.

<u>Forestation</u> mitigation options are being implemented on wastelands and marginal crop and pasture lands with little aboveground carbon, but significant quantities of soil carbon that require stratified sampling or soil inventory data to represent the soil carbon density within the assessment boundary. (Ravindranath, Murthy, Sudha et al., and Sudha, Shubhashree et al., this issue). Alternatively, soil carbon estimates can be omitted to avoid transaction costs, and to produce a conservative carbon benefits estimate.

Most projects to date have used yield tables and other literature values for baseline stock change estimation, but as projects grow in number and complexity, use of forest or soil inventory data allows low-cost, transparent, baseline estimation from large, consistent, time-series data where they are available.

Forest management: Land use management mitigation practices are difficult to observe remotely (as are the initial years of forestation), since they do not involve land use change. Historical time trends or a model that relates changes in management practices to driving variables may be used to classify the rate of change of practices.

One potential land management baseline approach may be to identify the suite of management practices in use by land and management conditions, in existing datasets or through landowner or expert surveys, and estimate a baseline utilizing differential implementation of these practices over the land base (see Section 4.1 for an example). These suites of practices or land management intensity class (MIC, in the US FIA literature), for example, site preparation practices like clearing and burning for replanting tree mortality, fertilization, fire management can be ranked from low management intensity, to medium and high for a given set of biophysical and land use conditions.

GHG mitigation programs or analysts could assess various ways to combine or disaggregate data to produce simpler or more site-specific baseline values. They could explore using forest, management, ownership, and other variables they select based on biophysical or economic conditions, and their programmatic or policy objectives.

5. Synthesizing Work to Date

The regional baselines approach for LUCF projects improved the project-specific approach in two important ways. One, equations were developed for deforestation avoidance projects that related the deforestation rate to its key determinants within a spatial zone – distance to farms and roads, sawmill concentrations, export markets, etc. Two, for both deforestation avoidance and forestation projects, the spatial zone was stratified by land parcels that had a relatively uniform carbon density for each carbon pool.

Recently, the CDM has provided guidelines and approved three methodologies, and the WRI/WBCSD protocol has proposed a procedure for setting project-specific baselines and performance standards (Tables 2 and 3). Other major mitigation programs like the DOE 1605(b) guidelines include forest inventory-based look-up tables or tools. While the sequencing is not exactly alike, the steps for estimating baseline emissions for the CDM, 1605(b), and WRI/WBCSD protocol are relatively similar. The CDM approach requires establishing eligibility, defining the project boundary, using one of the three CDM baseline approaches (see Section 1-- Introduction), selecting carbon pools to be accounted for, stratifying project area where appropriate, selecting the most plausible baseline scenario, and estimating loss of carbon stocks due to risks such as fires and/or leakage.

The key differences in the three approaches are that the CDM (1) requires that the project meet conditions to ensure its additionality, and (2) does not set performance standards for its projects, and the 1605(b) guidance does not address additionality or require dynamic baselines over time. The CDM allows the use of regional baselines, however, as described in the case of the Moldova project above.

The estimation of regional baselines for forestry projects would be enhanced by the use of a systematic method for the setting of the (1) GHG assessment boundary and stratification of the included region, and (2) historical time period for input data and for baseline projection forward in time. The WRI/WBCSD protocol describes the use of a systematic approach for selecting the time period and region for electricity and industry projects based on the work by Murtishaw et al. (2005).

Below we describe the two enhancements with example applications for forestry projects.

5.1 GHG Assessment Boundary and Stratification of Land Area and Carbon Pools

Both data availability and model choice influence the selection of baseline candidates that lie within a certain assessment boundary. For projects whose reference activities vary primarily due to anthropogenic factors, such as the location of saw mills or resettlement of forest lands, national or other administrative boundaries may constitute an appropriate assessment boundary. Brown et al. (this issue) describe the use of three different models that use different GHG assessment boundaries. The FAC model is applied at the national or regional level, whereas the other two LUCS and GEOMOD may be applied at the project or neighboring area level. A second type of boundary is defined by physical infrastructure. In the analysis of the Lower Yazoo River Basin (LYRB) on the Mississippi River, Sommer et al. (2004) use the LYRB area due to its unique bounding by a set of dikes to protect agricultural land from flooding. Deforestation rates are much higher along roads and river valleys and diminish as one moves away from them (Brown et al., 2000). Models of deforestation make explicit use of this and other aforementioned parameters in projecting future changes in land use (de Jong, 2002). Finally, biophysical characteristics like agro-climatic or ecological zones may define a project boundary that cuts across administrative and infrastructure networks.

Stratification permits the grouping of land parcels into those that have similar characteristics such as types and/or rates of change of carbon pools, and similar drivers for land use change. Models of deforestation and forestation described in the summary classification Table 4, for instance, evaluate which drivers best explain land use change patterns. The resulting stratification is used to group land use change by the probability of transformation of one type into another. The example below illustrates stratification of forest inventory data in order to develop a baseline of forest growth rates.

5.1.1 Example of stratification approach using inventory data

Table 5 provides an illustrative example of how forest inventory or other data could be stratified to develop a baseline of forest growth rates (and/or management intensity, if practice data are available) for a land-use mosaic of different forest types and practices. In this example, forest productivity classes (i.e., high to low growth rates) were used to stratify the data for three bottomland forest types on private lands, for two samples --the 4 counties in Mississippi in the Sommer et al. (2004) study, and 29 counties in South Carolina likely to have similar bottomland forests. Total aboveground carbon per hectare was selected (mean value was chosen purely for demonstration). The revised DOE 1605(b) look up tables and calculator tools are derived from or manipulate national forest and soil inventory data, in combination with modeling (for soil management projects like introducing low-tillage systems).

TABLE 5:

Stratification approach using inventory data*

Insert here

The USDA Forest Service's Forest Inventory and Analysis (FIA) units produce the inventory of U.S. forest lands every 5 years for 120,000 forest sample points each representing 2200 ha (http://fia.fs.fed.us). The NACSI Carbon OnLine Evaluator tool website[10] developed for the USDOE 1605(b) voluntary reporting program for GHG mitigation in the U.S. allows custom manipulation of FIA data by carbon pools, forest type, ownership, stand age, site productivity, and other attributes.

In this example, forest productivity classes (i.e., high to low growth rates) were used to stratify the data for three bottomland forest types on private lands, for two samples. Table 5 illustrates that inventory data vary by forest type, productivity class, and location, allowing stratification. Some classes like oak-hickory in Mississippi (productivity below 15.6 m^3) have a precision metric like standard error that is low (6.0-9.1), and might be useful for setting a baseline value for that forest type in that location. Others (e.g., 15.7+ m^3 productivity in that type) have far higher standard errors (42.1 in this case) and thus may be less useful or require additional variables.

This approach could be used to estimate a forest management project poor- to best-management class regional baseline, as well, or a performance standard emissions rate in the WRI/SBCSD Protocol context. FIA data also record stand management intensity, including treatment practices within the last 5 years like cutting (harvest), site preparation, artificial regeneration, natural regeneration, and other silvicultural treatments (e.g., use of fertilizers or herbicides), and potential treatment opportunities not undertaken (Alerich et al., n.d.).

GHG mitigation programs or analysts could assess various ways to combine or disaggregate data to produce simpler or more site-specific baseline values. They could explore using forest, management, ownership, and other variables they select based on biophysical or economic conditions, and their programmatic or policy objectives.

5.2 Determining the temporal period and GHG assessment boundary

Historical period: Project-specific and regional baseline analyses to date have not offered a logical framework for determining the historical time period to be used for setting a baseline, or the future validity period for a baseline once established. Restricting the temporal period of reference activities can provide a more representative range of values that are likely to occur in the near future. For land use change projects, this has two dimensions: the rate of change of carbon stock may vary over time, and the transition from one land use to another may change. Busch et al. (1999) for instance note that the rate of deforestation in Costa Rica had been declining steadily since the early 1950s, and using an older rate would significantly overestimate the rate of future deforestation and hence the amount of emissions avoided.

Murtishaw et al. (2005) discuss the use of break or inflexion points in key variable trends to define the temporal period in energy and industry sectors. Figure 3 shows four possible trends in the average annual emissions rate: 1) relatively stable over the period (noted by Ravindranath, Murthy, Sudha, et al. (this issue) for southern India), 2) a steady downward trend (noted by Busch et al. (1999) for deforestation in Costa Rica), or 3) a scattering of carbon emissions rates (illustrated by Fearnside (2000) for deforestation in the Amazon). In the stable case, the choice of the number of years will not have much impact on the SRB emissions rate; the steady trend case suggests the use of fewer years to estimate the future emissions rate since including data from too many years back would tend to overestimate the rate; and the scattering case suggests that a greater number of years' worth of data may be necessary to obtain an average representative of the range of changes

<u>Inflexion or break point:</u> The fourth pattern is a clear inflexion point that emerges in the plot of the annual emissions rates--. when the trend suddenly changes. If a inflexion point can be clearly identified, it defines the earliest year that should be included in the estimation of the baseline. For instance, Figure 3 shows that the downward trend that occurs during the first five time periods stabilizes from period 6 on. The changes in period 6 constitute a break point in the historical trend in emission rates

Insert here

Figure 3: Alternative schematic patterns of historical emissions rates

Inflexion or break points may be caused by policy changes such as resettlement policies for forest lands in Kalimantan, Indonesia in the 1980s, the passing of a forest conservation act in India in 1980;, or of a logging ban in China in 1999.. Alternatively, a break point may occur due to autonomous changes in product demand, commodity prices, or land use practices. An increase in demand for agricultural products (soya beans) from Brazil increased deforestation rates in the 1990s. The planting of clonal varieties of eucalyptus in the ITC case reported by Sudha, Ramprasad, et al. (this issue) reduced its rotation period to four years, which has made the practice cost effective and an attractive alternative to leaving land barren in Andhra Pradesh, India. The setting of baselines needs to take such events and market fluctuations into consideration in estimating both the changes in land use and carbon density.

<u>Future Validity Period:</u> The validity period for a baseline is dictated by the frequency of data collection and policy changes. The long gestation periods of some types of land use change projects, and the need for a stable investment climate for investors, argue that baselines should

remain fixed over many decades. On the other hand, new policies and autonomous changes in practices and technologies may bring about significant changes in land use and carbon density patterns much sooner. Another factor to consider is the time interval between episodic data collection like remote sensing data from satellites, or forest or soil data from inventories at two- to ten-year intervals.

The validity period of a baseline (before its review is encouraged or required) is likely to be set by a GHG mitigation program, as a tradeoff between environmental stringency and investment certainty. Brown et al. (this issue) suggest consideration of 10 years. The CDM allows 30 year project periods, or 20 years plus two 20-year renewals. Aggregators sign five- or six-year contracts with individual farmers for introducing and maintaining low-tillage plowing systems in the U.S. Midwest for sale to the CCX, while the Pacific Northwest Direct Seeding Association's low-till project in the U.S. signs 10-year contracts with farmers (Dale Enerson, North Dakota Farmers Union, personal communication, 2006). Mitigation activities with long rotation or gestation periods like reforestation are likely to be feasible only in longer validity periods, illustrating the investment implications of this decision. Programs eventually are likely to establish guidance on evaluation of the baseline once the validity period expires, perhaps through review of key input variables. An alternative might be to set a limit on the magnitude or percentage change in the values of key driver variables for a given confidence interval—a zone within which they could float, but would need to be revised if they exceed it.

5.3 Potential steps for setting a SRB emissions rate for LUCF projects:

Summarizing the regional baseline experience to date, we list the following steps for estimating a SRB emissions rate (recognizing that method details vary by mitigation activity and land use, per the Table 4 classification). These steps have counterparts in, for example, the WRI/WBCSD Project Protocols, which use different terms in some cases, but are largely consistent.

Task I: Establish a stratified baseline emissions rate

1. Define the GHG emissions assessment boundary: The selection of the assessment boundary will be guided by the data available for stratification of land by characteristics, and the number and types of potential LUCF projects that are expected to emerge within the boundary. The boundary will also depend on existing biophysical, infrastructure, and administrative boundaries in the neighborhood. Examples of alternative boundaries are discussed in Section 4.1.

1a. Specify the appropriate metric to be used for defining the baseline. For land use change and forestry projects, the appropriate metric usually is the annual change in carbon stock per unit land area, which may be expressed in t C sequestered or emissions avoided per hectare of land per year (t C/ha/yr). Multiplied by the annual land use change (ha/yr), the expression results in the baseline change in carbon stock (t C).

1b. Specify the carbon pools and GHGs to be included. These may be specified by a mitigation program targeted by a project, and/or based on the available data. Generally five carbon pools are considered (above- and below-ground biomass, dead wood, soils, and litter), and wood products added if significant, or a pool excluded if minor or uncertain. Soil carbon is expensive to sample and carbon stock changes are minimal per hectare, so it often omitted, producing a conservative carbon benefits estimate. GHG benefits of forestry projects generally have thus far been limited to the accounting of changes in carbon stocks. For projects that use agricultural land, a baseline may have significant quantities of other GHGs, methane in particular, which would argue for the inclusion of non-CO_2 gases as well.

2. Stratify the GHG assessment region to account for spatial variability of a) land use change, and b) GHG emissions and removals, including carbon density (t C/ha). The level of stratification will be determined by the uniformity of land use change and GHG emissions and removals (especially carbon density) for a given carbon pool. For example, to the extent the baseline above-ground biomass carbon density is constant within the boundary, the uncertainty bounds around a SRB emissions rate will be narrower (demonstrated in Table 5). Where the

density for a carbon pool varies at random across the region, sampled data would yield a wider uncertainty range around the mean estimate.

3. Define a temporal period for the estimation of a *historical* land use change rate, and GHG emissions and removals rate (t C/ha/yr), and their *projection* forward as a baseline.

The temporal period to be used for setting a SRB emissions rate will depend on factors and use methods described in Section 4.2. If there is a definite trend in historical land use change rate, then it would be advisable to follow this trend to determine a future rate unless a policy change that would affect this trend is imminent and knowable. If there is no clear trend, an average rate of past trends may be used. Likewise, if there was a policy change in the past that significantly altered the trend, then the analysis of historical data should start after this break point.

The minimum future time period of validity for the baseline will be dictated by GHG mitigation program rules and by the intervals over which data become available, which may be five years or more for deforestation reduction projects that rely on remote sensing imagery, The maximum period will depend on program rules and the frequency of changes in the driver variables.

4. Establish a historical baseline carbon emissions rate (t C/ha/yr) based on Steps 3 and 4 above.

Task 2: Estimate a SRB emissions rate:

Once the historical emissions rates have been analyzed and determined --with appropriate uncertainty bounds for each stratified land parcel-- a future emissions rate needs to be established.

5. Project future baseline emissions rate: A future baseline emissions rate may be estimated using a single average historical value or simple extrapolation of the time trend. Where more sophisticated modeling has been done, the rate may be based on key driver variables. In each case, it is important to estimate the uncertainty range around the projected mean value, time trend or the value dependent on driver variables. Steps 1 through 4 yield an emissions rate (t

C/ha/yr) with uncertainty bounds. The WRI/WBCSD Project Protocols' performance standard procedure and the sector guidance for land use and forestry that supplements it (WRI, 2006) accomplish this step and then calculates a set of environmental stringency values (i.e., how strict to set the regional performance standard) for the mean carbon stocks, median stocks (50th percentile), the most stringent (highest stocks), and two other better than average percentiles (e.g, 75th and 90th percentiles) (WRI, 2006).

An assessment region with uniform carbon density and similar land use change patterns will yield lower uncertainty bounds and vice versa. For example, Sommer et al. (2004) note that in their analysis of the LYRB, the 95% upper bound yields almost twice the afforestation rate compared to the mean value. Using the higher afforestation rate would decrease the carbon benefit that a project could claim, providing a conservative estimate.

For a deforestation project, where the rate of deforestation is related to driver variables, a confidence interval around the trend line could be used. A lower rate of deforestation would constitute a stringent standard and vice versa.

A SRB emissions rate may be determined using historical data or near-future estimates of land use and carbon density change. Sophisticated models such as GEOMOD and others project rates and locations of future deforestation given historical conditions (Brown et al., this issue). An alternative to the use of such models is to estimate the historical rate of deforestation or forestation and use this rate for the near-future period. If the historical SRB emissions rate is coupled with the adjustment procedure described below in Step 6, the resulting estimated carbon benefit will lag by a few years at most, but will be far more certain than a benefit based on estimates of future trends.

6. Review and adjust the SRB emissions rate. The estimated rate may need to be adjusted periodically if there is a significant change in its value, as discussed above.

6. Case Study of the Feasibility of a Stratified Regional Baseline

To illustrate these steps with actual data, we use the hypothetical LYRB afforestation project study performed by Sommer et al. (2004), and utilized in the WRI/WBCSD Project Protocols Roadtest process (2004) as a case study. This analysis assessed the potential for converting frequently flooded marginal croplands back to native bottomland hardwood forest of the Mississippi Alluvial Valley in south-central U.S. by planting Nutall Oak and other species.

1. Define the GHG Assessment Region: Some 5,427 ha[11] were evaluated in a four-county area between the Yazoo and Mississippi rivers near Vicksburg, Mississippi. Of this area, 790 ha met the selection criteria of economically marginal croplands that flood on average every two years, causing severe crop damages. These lands were identified as falling within the two-year floodplain, using Digital Elevation Models to provide cropland elevation relative to river elevations.

The potential project case (no effort was made to fund or undertake this activity) assumed planting of hardwood plantations that would either be harvested on a 60-year rotation (at maximum timber yield) or remain in forest, and generate payments for carbon sequestration benefits. Two baseline options were assessed: 1) cropland remains cropland, or 2) cropland is converted to forest. Land-use data were accessed in the publicly available National Resources Inventory (NRI) of the U.S. Department of Agriculture (USDA), which provides data on 800,000 sample points on five-year time steps from 1982 up to 1997.

1a. Specify the appropriate metric: Afforestation per county per year, and carbon flux on these lands in t C/ha yr^{-1} were selected as the metrics.

1b. Specify the C pools and GHGs to be included: Five C pools modeled in the USDA FORCARB model (trees, understory, litter, coarse woody debris, and soils) were selected.

2. Stratify the GHG assessment region to account for spatial and other variability, into homogeneous units: Using discrete choice logit regressions, the authors estimated the probability of target croplands undergoing conversion to forest as a function of cropland characteristics. By

adding cropland elevation and hence the flooding frequency variable, the probability of cropland conversion to forests increased, and was highly significant statistically but required only two driver variables.

Differential county baseline afforestation rates were generated by the analysis over the 15-year historical data period, and range from 0.26% - 1.76% annual afforestation of the frequently flooded croplands as shown in Table 6, or 3.9% - 26.4% cumulatively over the 15-year period. This should factor out any reforestation undertaken in anticipation of a future carbon market.

TABLE 6.

LYRB project four-county sample historical baseline annual afforestation rates, 1982-97

Insert here

<u>3 and 4. Define the temporal period, and Establish historical baseline temporal period and C emissions or sequestration rate (t C/ha/yr) based on key driver variables.</u> The temporal period was dictated by available data on land use change at five-year intervals, for 1982-97. The USDA Forest Service empirical simulation Forest Carbon model (FORCARB) was used to track forest carbon stock change from afforestation on the 787 ha target area over this period.

<u>5. Project future baseline emissions (sequestration) rate:</u> The historical baselines by soil type are then assumed to be representative, under the assumption of constant climate. FORCARB was used to project forest carbon stock change from afforestation in the target area for the first ten years of the potential project (Table 7).

TABLE 7.

Baseline vs. project carbon calculation for LYRB Mississippi case study

Insert here

<u>6. Review and adjust the SRB emissions rate</u>: This step was not explicitly undertaken by Sommer et al., whose analysis projected the baseline out over 10 and 60 years. We use their data to illustrate the application of this step.

The Sommer et al. (2004) analysis projected the baseline out over 10 and 60 years, estimating that 1,509 t C would be accumulated by baseline afforestation by year 10 (and 41,938 t C in the project case, using the mean afforestation rate). Figure 4 illustrates relatively small divergence of carbon benefits above the baseline between the two approaches at 10 years. But the project-specific approach provides significantly more carbon benefits at 60 years, since it assumes the area remains in agriculture, while the regional or performance standard analysis uses a projection of mixed agriculture and afforestation. The figure presents baseline afforestation evaluated at the mean and upper bound estimate from the logit regressions.

Insert here

Figure 4. Comparison of project-specific and regional approach for estimating baseline and project carbon sequestration (additional to baseline), for 10- and 60-year time horizons, for the Mississippi LYRB case study

The baseline driver variable values potentially could be reviewed at some interval (e.g., 5, 10 or more years), or under some conditions of change in key variables, most likely set by a given climate mitigation program. Some variables (e.g., cropland elevation) are unlikely to change over time or need review. As an illustration, reviewable driver variables in this case study might include, e.g., a) afforestation rate by county in out years (e.g., as the next NRI data are made public for 2002 (not yet public) and are scheduled for 2007); b) C stocking on croplands or afforested lands; c) changes in key socioeconomic or biophysical variables like crop prices or afforestation subsidies, that might suggest the BAR be expanded or contracted.

Application of the generic SRB approach is summarized in Table 8. Data appear to be available for each step of the methodology. But the Sommer et al. study was undertaken by RTI and USEPA as a methods development exercise, so additional cases would need to be evaluated to assess the method's usefulness and limitations.

TABLE 8:

Testing SRB methods using the Mississippi afforestation case study

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7. Conclusions

This paper reviews project specific and regional baseline emissions methods and literature, and synthesizes the latter into potential steps for estimating a stratified regional baseline (SRB) emissions rate.

Regional approaches provide more objective, standardized and transparent methodologies than the project-specific experience to date (although CDM AR methodologies are evolving rapidly). Regional approaches may have a high first cost, but potentially offer lower costs when amortized over multiple projects within a broader area. The higher transaction costs of setting project specific baselines are likely to reduce the number of forestry projects that attract investment flows, and smaller projects are likely to be particularly affected by these costs.

The discussion stresses the need for standardization of methods for each step of the baseline estimation process. Key decisions requiring guidance from GHG mitigation programs or other sources in the setting of SRB or other baseline approaches include the choice of the GHG assessment region or boundary, which will depend on the availability of data and its suitability for the model or method used for establishing rates of land use change. Spatial boundaries need to be broad enough to include all relevant reference activities so that the variation in emissions rates within the boundary is reflected in the SRB emissions rate. Guidance by GHG programs also may be needed on how projects should undertake the stratification of complex land use mosaics into relatively homogeneous parcels with roughly similar biophysical and other characteristics, a key step in the analysis.

The trends in historical land use change and the rates of deforestation or forestation provide guidance on the historical period that should be used for setting the SRB. If statistical analysis of emissions rates shows a stable trend, then any recent period could be used to determine the SRB emissions rate. However, when there is a clear break in a historical trend, it is important to determine when the break occurred, why it occurred, and whether the change is likely to be stable or not, and set the baseline accordingly. A break due to a prolonged drought may not indicate a permanent change in the trend, but one caused by a technological breakthrough or change in land use practice might be an indicator of a new emerging trend. In this case, the temporal period should extend back no further than the appearance of the break point.

GHG mitigation programs should set the baseline validity period long enough to cover the data collection intervals and provide certainty for GHG market investors but short enough to accommodate changes in government policies or commodity prices. These needs argue for relatively short baseline projection periods, or options to renew a project and baseline, and for GHG programs to specify guidance on the conditions under which a baseline would need to be revisited and revised if key baseline driver variables change significantly.

<u>Potential Future Work:</u> Topics for potential additional analyses that would advance the conceptualization and allow drafting of guidance on development of SRB include:

- Test the SRB approach on a range of mitigation activities and regional combinations
- Compare project specific vs. SRB approaches for the same case studies to understand the differences in estimation of GHG emissions baselines by each approach (e.g., expanding work in the Brown et al. (this issue), and Sudha, Shubhashree, et al. (this issue) papers).
- Assess data availability by major mitigation activity (e.g., reduced deforestation, afforestation, etc.) by region for the methods discussed here.
- Explore how to set guidance for using historical data break points in setting future dynamic baselines
- Estimate the cost, data and analytic requirements, of developing SRBs for these cases
- Collect data to allow the inclusion of transaction costs in these analyses, to see how such costs vary by baseline methods.

- Explore the use of management intensity classes, best practices or other approaches for forest management mitigation, as yet little considered.

The results of the analyses proposed above could inform the evolution of regional baselines for different project types, conditions, regions, and GHG mitigation program objectives.

Notes

[1] We use the term "emissions rate" throughout to mean net GHG emissions and removals, which can be an emission (e.g., for reduced deforestation) or a removal (e.g., for reforestation.)

[2] http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

[3] Regional baselines reduce the transaction costs of setting individual baselines for each project within a spatial zone, and provide a transparent and common basis for estimation of baselines for a class of projects within the zone.

[4] http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_AM_521G64I2VT53AZ88A9YHXZWNX9ZBUB

[5] This need not always be the case. The Pearl River CDM methodology, for example, relatively simply demonstrated that the distance to timber markets makes reforestation unattractive, past government efforts to reforest the area failed due to barriers, and the IRR of the project without carbon benefits was too low to obtain a loan (Schlamadinger, 2006, Personal communication.)

[6] An evaluation of a number World Bank-managed Prototype Carbon Fund projects found that the costs associated with preparing a project-specific baseline study and presenting a case for environmental additionality are about US$20,000 per project (World Bank, 2000). Uncertainty related to calculation of emissions reductions using project-specific baselines has been estimated to range from ± 35% to ±60% for demand-side, heat supply, cogeneration, and electricity supply projects (Parkinson et al., 2001).

[7] USDA Natural Resource Conservation Service (NRCS) National Resources Inventory (NRI) datasets for above ground carbon and soil data, coupled with STATSGO for additional soil characteristics.

[8] WRI/WBCSD Protocol terminology for using a regional approach to set an emission rate standard.

[9] For Decision text, see http://unfccc.int/meetings/cop_11.

[10] http://ncasi.uml.edu/COLE/cole.html

[11] 1 hectare = 2.54 acres

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References

Alerich C, Klevgard L, et al, The forest inventory and analysis database: Database description and users guide version 2.0. http://ncrs2.fs.fed.us/4801/FIADB/fiadb_documentation

Antinori C, Sathaye J, et al (2006) Assessing transaction costs of project-based greenhouse gas emissions trading. Lawrence Berkeley National Laboratory LBNL-57315

Bailey RG, Avers PE, et al. (eds) (1994) Ecoregions and subregions of the United States (map). Washington, DC, U.S. Geological Survey. Scale 1:750,000; colored. Accompanied by a supplementary table of map unit descriptions compiled and edited by McNab WH, and Bailey RG. Prepared for the U.S. Department of Agriculture, Forest Service

Brown S, Calmon M, et al (1999) Development of a deforestation and forest degradation trend model for the Guaraquecaba Climate Action Project. 14 pp. Winrock International Carbon Monitoring Program. Arlington, VA. USA

Brown S, Burnham M, et al (2000) Issues and challenges for forest-based carbon offset projects: A case study of Noel Kempff Climate Action Project in Bolivia. Mitigation and Adaptation Strategies for Global Change

Brown S, Masera O, et al (2000) Project-based activities. In: Land use, land-use change, and forestry. R. Watson, I. Noble, B. et al. (eds) Printed by Cambridge University Press for the Intergovernmental Panel on Climate Change

Busch C, Sathaye J, et al (1999) Lessons for greenhouse gas accounting: A case study of Costa Rica's protected areas project. Lawrence Berkeley National Laboratory, Berkeley, CA. LBNL 42889

Davidson E (1995) Spatial covariation of soil organic carbon, clay content, and drainage class at a regional scale. Landscape Ecology. 10(6):349-362

de Jong B (2002) A landscape-based analysis of temporal and spatial variation of deforestation and carbon budgets: An approach for multi-project baselines

International symposim on forest carbon sequestration and monitoring, 13-15 November, 2002, Taipei, Taiwan

Figueres C, (2006) Sectoral CDM: Opening the CDM to the yet unrealized goal of sustainable development. Special Issue on Climate Change, International Journal of Sustainable Development Law and Policy, Vol. II, Issue 1.

Kaimovitz D, and Angelsen A (1998) Economic models of deforestation. a review. CIFOR, Indonesia

Kartha S, Lazarus M, et al., (2002) Practical baseline recommendations for greenhouse gas mitigation projects in the electric power sector. OECD/IEA Information Paper. http://www.iea.org/envissu/ghgmit.pdf

Moura-Costa PH, Yap SW, et al (1996) Large scale enrichment planting with dipterocarps as an alternative for carbon offset-methods and preliminary results. In: Proceedings of the 5th Round Table Conference on Dipterocarps. Chiang Mai, Thailand, November 1994, Appanah S, and Khoo C, (eds). Forest Research Institute of Malaysia (FRIM), Kepong, Thailand. Pp. 386-396

Murtishaw S, Sathaye J, et al (2005) Spatial boundaries and temporal periods for setting greenhouse gas performance standards. Energy Policy. LBNL-54844

NACSI, n.d. Carbon online evaluator tool website. http://ncasi.uml.edu/COLE/cole.html

Parkinson S, Begg K, et al (2001) Accounting for flexibility against uncertain baselines: Lessons from case studies in Eastern European energy sector. Climate Policy 1:55-73

Pinard M, and Putz F (1997) Monitoring carbon sequestration benefits associated with reduced-impact logging project in Malaysia. Mitigation and Adaptation Strategies for Global Change, 2:278-295

Programme for Belize (1997) Rio-Bravo carbon sequestration pilot project offsets attributable to project actions for project year (1996). Report of the US Initiative on Joint Implementation and the Government of Belize, Belize City, Belize, 15 pp

Ravindranath N., Murthy I., et al (In press) Carbon price driven mitigation potential of forestry sector in India according to GTAP and India AEZ land classification systems. (This issue)

Ravindranath N H., Murthy I. K., et al (In press) Methodological issues in forestry mitigation projects: A case study of Kolar district. (this issue)

Schlamadinger B (2006) Personal communication. May

Sudha P, Shubhashree D, et al (In press) Regional baseline for the dominant agro-ecological zone of Karnataka, India, (this issue)

Sudha P, Ramprasad V, et al (In press) Methodological issues in developing industry promoted farm forestry mitigation project. (this issue)

Sommer A, Murray B, et al (2004) Project specific or performance standard baseline? Testing the alternatives for a forest carbon sequestration project. Prepared for proceedings of 3rd DOE Carbon sequestration Conference, May 3-6, 2004, Alexandria, Virginia, USA. http://www.epa.gov/sequestration/baselines.html

Tipper R, and de Jong BH (1998) Quantification and regulation of carbon offsets from forestry: Comparison of alternative methodologies with special reference to Chiapas, Mexico. Commonwealth Forestry Review, 77:219-228

US DOE (2006) Enhancing the Department of Energy's voluntary reporting of greenhouse gases (1605b) program. http://www.pi.energy.gov/enhancingGHGregistry/index.html

van Soest D (1995) Tropical rainforest degradation in Cameroon. Tilburg University, Department of Economics, The Netherlands. Processed

World Bank (2000) Learning from the implementation of the Prototype Carbon Fund. World Bank, Washington DC

World Resources Institute/World Business Council for Sustainable Development. (2003) The greenhouse gas protocol: project quantification standard. Road Test Draft, September. 143 p. Available via www.ghgprotocol.org

World Resources Institute (WRI) (2006) The land-use, land-use change and forestry guidance for project accounting. World Resources Insititute, forthcoming November 2006

World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), (2005) The GHG Protocol for Project Accounting. World Resources Institute. Washington, DC, November

Captions

Figure 1. Accumulated baseline emission estimations for Juznajab la Laguna, Chiapas, Mexico.

Figure 2. Role of GHG assessment region selection decision on baseline estimation: Example of Noel Kempff project, Bolivia.

Figure 3. Alternative schematic patterns of historical emissions rates.

Figure 4. Comparison of project-specific and regional approach for estimating baseline and project carbon sequestration (additional to baseline), for 10- and 60-year time horizons, for the Mississippi LYRB case study.

Table 3. Key characteristics of two general approaches for setting baselines.

Table 4. Project-specific baseline methods used by selected climate change projects, over time.

Table 3. Regional baseline methods for selected projects.

Table 4. Classification of regional baseline methods, by land use, for estimating land use change and carbon stock change.

Table 5. Stratification approach using inventory data*.

Table 6. LYRB project rour-county sample historical baseline annual afforestation rates, 1982-97.

Table 7. Baseline vs. project carbon calculation for LYRB Mississippi case study.

Table 8. Testing SRB methods using the Mississippi afforestation case study.

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Figure 1 Accumulated baseline emission estimations for Juznajab la Laguna,

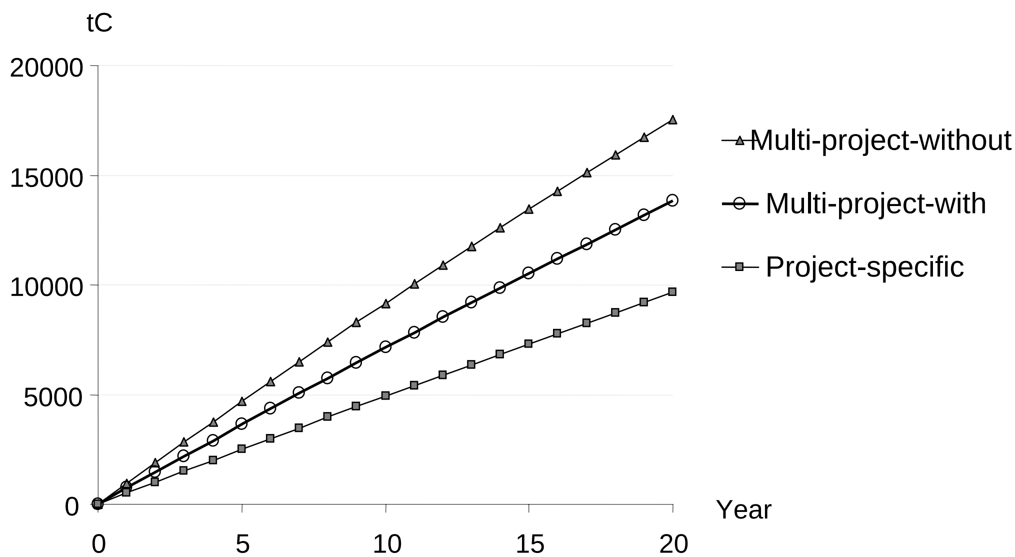


TABLE 5

Key characteristics of two general approaches for setting baselines

Key Characteristics	**Project-specific Approach**	**Regional Baselines Approach**
Programmatic Use	Already in use by programs to set baseline emissions, e.g, AIJ, CDM, Climate Trust. Option in WRI/WBCSD Protocols.	Demonstrated by analytic studies. In use to some extent by DOE 1605(b) and WRI/WBCSD guidelines. [[speculation]]:
Baseline developer	Project developer. For CDM, propose new or use approved baseline methodology.	Project developer and/or aggregator
Transaction Costs	High, could decline if methods standardized.	Low where multiple projects exist
Transparency	Low, but may be high if program requires it, e.g., CDM	Medium, but may be high if program requires it.
Consistency of baselines for similar projects	Not assured, unless standardized methods are required (e.g., approved CDM methodologies)	Likely
Accounting region for setting baseline	Project area generally. WRI uses project boundary of GHG effects.	Spatial zone larger than project
Use of stratified baselines	Used for large projects with multiple options and carbon pools within a project area	Likely, since spatial area is larger and hence the likelihood of multiple options and carbon pools is higher
Temporal period for input data	Ad hoc approach	Ad hoc approach
Future validity period	Policy choice depending on periodicity of input data and likelihood of changes in determining factors at the project site	Policy choice depending on periodicity of input data and likelihood of changes in determining factors in the spatial zone
Potential for multiple projects within spatial zone	None. But CDM accepted method can be applied elsewhere.	None

Notes: 1) CDM: means Clean Development Mechanism of the UNFCCC; see http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

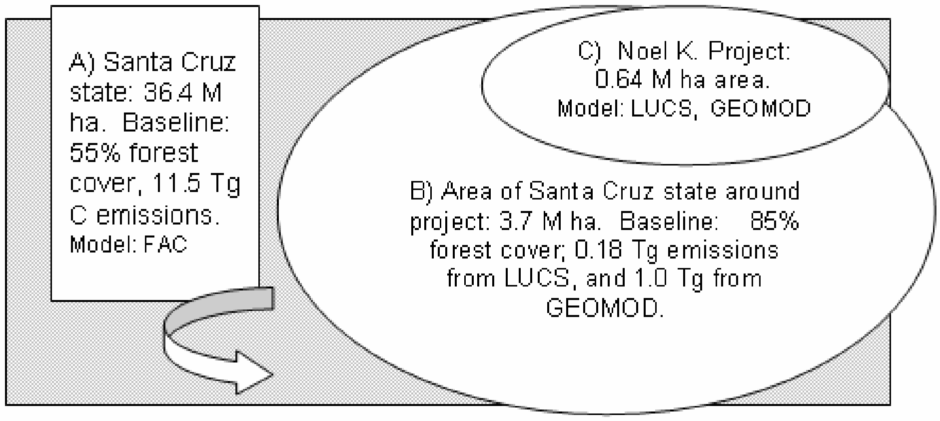
TABLE 6:

Project-specific baseline methods used by selected climate change projects, over time

Project Name	Project Category	Methods and key variables used to establish baseline	Fixed or Adjustable	References
INFAPRO Rainforest Rehabilitation, Malaysia	Forestation	Simple logical argument assuming business as usual trends; quantification of baseline carbon in control plots	Fixed	Moura Costa et al. (1996)
Rio Bravo Sequestration Project, Belize*	Avoided Deforestation	Simple logical argument assuming business as usual trends	Fixed	Programme for Belize (1997)
Reduced Impact Logging, Sabah, Malaysia	Avoided Deforestation	Simple logical argument assuming business as usual trends; quantification of baseline carbon in control plots	Fixed	Pinard and Putz (1997)
Protected Areas Project (PAP), Costa Rica	Avoided Deforestation	Extrapolation of estimated historical deforestation rates	Alternative baseline scenarios	Busch, Sathaye, Sanchez-Azofeifa (1999)
Guaraquecaba Climate Action Project, Brazil*	Multi-component	Spatial land-use models incorporating socioeconomic factors	Adjustable, to recalibrate model at frequent intervals	Brown et al. (1999)
Noel Kempff Climate Action Project, Bolivia*	Avoided Deforestation	Simple logical argument based on adjusting observed trends, quantification of baseline carbon in proxy areas	Adjustable, based on changes of demand for timber, changes in marketable species, forest law, and rates of deforestation	Brown et al. (2000)
Scolel Te (Plan Vivo Project), Chiapas, Mexico*	Forestation	Identify and map current land use based on farmer surveys and project future land use	Adjustable	De Jong (2002)
Lower Yazoo River Basin (LYRB), Mississippi, USA* (hypothetical project)	Afforestation	Barriers analysis of farming and forestry baseline options, all lands deemed marginal for farming are planted.	Fixed, although report notes the need to make baseline adjustable	Sommer, Murray, and Andrasko (2004)
WRI/WBCSD GHG Protocol: project-specific procedure	Afforestation, forest management		Identify baseline candidates. Compare barriers to project activity, and select a baseline scenario. Estimate baseline emissions.	WRI/WBCSD, 2005; draft forest sector protocols (2006)
Pearl River Basin Reforestation, China. CDM Methodology	Reforestation of degraded lands	CDM baseline approach (a): existing or historical changes in C stocks within project boundary. Stratified land eligibility factors. Used	Fill in FILL IN	http://cdm.unfccc.int/methodologies/ARmethodolo

ARAM0001.		CDM additionality tool		gies/ approved_ar. html
Upper Magat Watershed, Luzon, Philippines (hypothetical project)	Decrease deforestation and pursue forestation	Simple extrapolation of historical 10-year land use change trend (1988-98) to 2030.	Fixed	Lasco et al. (this issue)

* -- These projects are listed in both Tables 2 and 3 since they demonstrate the use of both project-specific and regional baselines approaches.



Note: 1) project area (C, in million ha) is 1.8% of largest BAR (case A), using the FAC population-drive statistical model of forest cover change; subregion area (B) is roughly 10% of state GHG assessment region (A). Baseline of initial forest area percentage (Baseline) and emissions from expected deforestation over 20 year period in Tg are given.

Source. (Brown et al., this issue)

TABLE 3:

Regional baseline methods for selected projects

Location (reference)	**Project Type**	**Methods and Key Variables Used to Establish Baseline**	**Advantages and Disadvantages of Methods**
Chiapas: Multiproject baseline (Tipper and de Jong, 1998)	Avoided Deforestation	Extrapolation of historical time trend over 300,000 ha highlands region of Chiapas	Advantages: Simple time trend extrapolation Disadvantage: Ignores heterogeneity caused by “pre-disposing” and “driving” factors within region.
Chiapas: Multiproject baselines (de Jong, 2002)	Avoided Deforestation	2-factor approach to estimate vulnerable land area coupled with sample measurements of biomass and soil carbon. Factors are distance to transportation networks and proximity to agricultural lands.	Advantages: Limited spatial data requirements may be gathered from government statistics and maps Disadvantages: Temporal period and spatial zone not investigated.
Six sites in Latin America Tropics; one each in Belize, Bolivia, and Brazil and three in Mexico, (Brown et al.; this issue)	Avoided Deforestation	Forest Area Change (FAC); uses historical data on forest cover and population density as the driver variables.	Advantages: Minimal data requirements, lower costs, applied to large regions. Disadvantages: Lack of spatial resolution, reliance on only two variables, temporal period not investigated.
As above	Avoided Deforestation	Land-use Carbon Sequestration (LUCS) uses current land use patterns, ag. land required, and ag. products trade as drivers, and relates per capita demand to	Advantages: Ability to model many types of land use changes at different scales. Disadvantages: Lack of spatial resolution, and assumptions about poorly-known parameters, temporal period not investigated..

		population growth	
As above	Avoided Deforestation	Geographical Modeling (GEOMOD): uses spatially distributed data to simulate landscape dynamics. Sorts many driver variables to select the ones with highest correlation to deforestation.	Advantages: Spatial resolution at any scale, and allows evaluation of model performance versus chance. Disadvantages: Large data needs, high model validation effort, higher cost for data acquisition and analysis Temporal period and spatial zone not investigated..
Jambi hypothetical case study, Indonesia; Boer et al. (this issue)	Avoided Deforestation, and forestation	Regional Baseline developed using site-specific data and remote sensing of historical land-use trends projected into future. Sorts many driver variables to select the ones with highest correlation to deforestation.	Advantages: Allows evaluation of baselines and leakage for many projects within a district. Disadvantages: Relies on driver variables and estimated parameters for deforestation projections, data intensive, requires remotely sensed data. Spatial zone is the administrative boundary, temporal period not investigated..
Andhra Pradesh State, India (Sudha, Ramprasad et al. this issue)	Forestation: Farm Forestry	Combine measured biomass and soil carbon sample density with simple extrapolation of past and current forestation rates.	Advantage: Particularly suited for degraded lands. Low above/below ground biomass carbon density with low uncertainty. Disadvantage: Potential for large variation in soil organic carbon estimate. Spatial zone defined by administrative boundary, temporal period not investigated.
Lower Yazoo River Basin (LYRB), Mississippi, USA; Sommer, Murray, and Andrasko (2004)	Afforestation	Combine measured soil carbon and biomass carbon density with satellite image analysis of historical land use change. Location and flooding frequency are used	Advantage: Spatial analysis is within a well defined spatial zone. Disadvantage: Temporal period of analysis based on data availability not investigated otherwise.

		as predisposing factors.	
WRI/WBCSD GHG Protocol: permanence standard procedure. WRI/WBCSD (2005); WRI, 2006.	Afforestation, forest management	Identify baseline candidates. Specify performance metric; calculate carbon stocks for each baseline candidate. Calculate carbon stocks for stringency levels; select stringency level. Estimate change in baseline carbon stocks	WRI/WBCSD, 2005; draft forest sector protocols (2006)
Moldova Soil Conservation Project. CDM Methodology ARAM0002. _	Restoration of degraded lands via afforestation	Two approaches: 1) historical practice by project proponent (project-specific, stratified lands and created baseline for each stratum);ollowing Pearl River project CDM methods.; and 2) regional or national background reforestation rates—regional approach.	http://cdm.unfccc.int/methodologies/ ARmethodologies/ approved_ar.html

TABLE 4:

Classification of regional baseline methods, by land use, for estimating land use change and carbon stock change

Avoided Deforestation		
	Quantifying Land Use Change (examples)	***Estimating Carbon Stock Change (examples)***
Undisturbed Forests	Model that relates rate of deforestation to predisposing and driver variables, logging may be the most likely cause of deforestation Examples: van Soest (1995); Kaimowitz and Angelsen, 1998	Above-ground biomass/BGB may be estimated using forest inventory data or measurements by forest SOC: Sampling or partial covariation approach may be used to estimate SOC Example: Davidson (1995).
Disturbed Forests	Model that relates rate of deforestation to predisposing and driver variables, agriculture and fuelwood demand may be the most likely causes of deforestation Examples: Brown et al., Boer et al. (this issue)	Carbon density based on measurement of above-ground biomass and SOC of a stratified sample of land cover and use Examples: Tipper and de Jong (1998)
Forestation		
Wasteland	Historical time trends, or use a model with explanatory variables: outmigration of rural population, seedling programs etc. Example: Ravindranath, Murthy, Sudha, et al.(this issue)	Carbon density based on measurement of above-ground biomass, and SOC is based on a stratified sample of land cover and use Example: Ravindranath, Murthy, Sudha, et al.(this issue)
Agricultural land	Historical time trends; or use a model with explanatory variables, geophysical characteristics and particular attributes such as flooding frequency Example: Sommer et al. (2004)	National land use inventory data or sample measurements of suitable land within a spatial zone Example: Sommer et al. (2004)
Forest Management		
Managed Forest	Historical time trend or use a model to project the rate of change in current management practice Example: USDA National Resources Inventory data	National land use inventory data or sample measurements of suitable land within a spatial zone Example: U.S. Forest Service FIA data (http://fia.fs.fed.us).

Source: Table 3 and references within it.
Notes: SOC = soil organic carbon. FIA = US Forest Service Forest Inventory and Assessment

TABLE 5:

Stratification approach using inventory data*

	Aboveground Carbon (mean) by Site Productivity Class (standard error of the mean)**				
Forest Type	**15.7+ m3/ha/yr**	**15.6-11.5 m3/ha/yr**	**11.4-8.4 m3/ha/yr**	**8.3-5.9 m3/ha/yr**	**5.8-3.5 m3/ha/yr**
Oak / Hickory Group : Mississippi (134,788 ha)	53.3 (42.1)	95.6 (9.1)	77.2 (6.0)	76.3 (7.8)	89.2 (8.1)
Oak / Hickory Group: South Carolina (294,103 ha)	-	-	80.6 (16.9)	68.2 (4.3)	56.8 (1.6)
Oak / Gum / Cypress Group: Mississippi (88,990 ha)	-	101.9 (10.5)	97.1 (11.8)	83.0 (21.4)	105.3 (13.1)
Oak / Gum / Cypress Group: South Carolina (717,658 ha)	7.4 (-)	72.1 (49.0)	106.4 (10.0)	99.41 (2.5)	96.9 (2.5)
Elm / Ash / Cottonwood Group: Mississippi (62,154 ha)	97.2 (3.9)	106.1 (15.6)	59.9 (22.0	77.3 (15.3)	85.1 (7.4)
Elm / Ash / Cottonwood Group: South Carolina (61,081 ha)	-	99.8 (-)	113.6 (51.6)	88.2 (6.6)	84.2 (4.9

Source: http://ncasi.uml.edu/ see Carbon OnLine Evaluator

Notes:

*Example of stratifying forest inventory data to estimate a baseline by forest type and productivity class (site conditions). This approach could be used for land use management data as well, if data on suites of practices are available by forest type or conditions.

** Mean total aboveground carbon (metric tons/hectare) for bottomland forest types, by site productivity class, for two samples: 4 counties in Mississippi , and 29 counties in South Carolina, using USF*S* FIA data and the COLE data analyzer. Number of hectares of type given in left column, and the standard error of the mean value is given in parentheses in the right columns.

Figure 3: Alternative schematic patterns of historical emissions rates

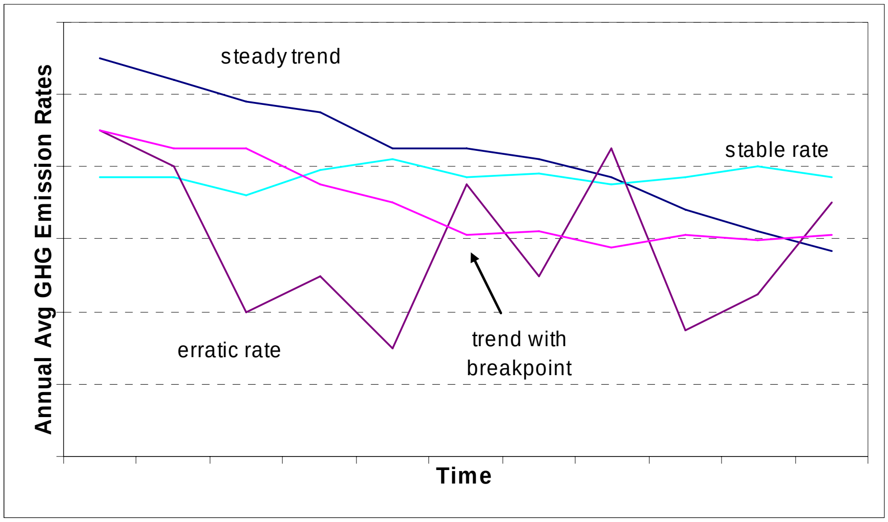


TABLE 6.

LYRB project rour-county sample historical baseline annual afforestation rates, 1982-97

	County			
	Issaquena	**Sharkey**	**Warren**	**Yazoo**
Mean	1.1%	0.26%	1.76%	0.76%
Upper Bound of Confidence Interval	4.62%	2.70%	4.68%	4.56%

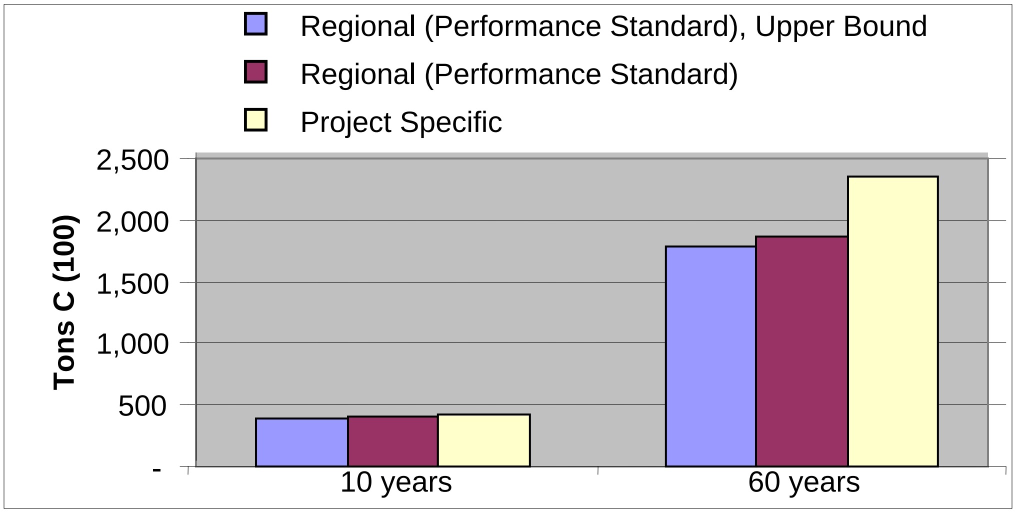
TABLE 7.

Baseline vs. project carbon calculation for LYRB Mississippi case study

Soil Type	**Project Area (ha)**	**Baseline (Historic, and Same Rate Projected Forward)**			**Project Activity and C**		
		Projected Afforestation by Year 10 (Acres; Mean)	C Gain Rate /ha Over 10 Years (t C/ha)	Projected C Accumulation by Year 10 (t C)	Projected Afforestation by Year 10 (ha)	C Gain Rate /ha over 10 Years (tC/ha)	Projected Afforestation by Year 10 (ha)
1	593	56	19.7	1,103	593	51.5	30,554
2	59	5.5	21.3	117	59	55.1	3,254
2	136	13	22.2	289	136	59.8	8,130
Total	787	75	20.1	1,509	787	53.3	41,938

Source: Sommer et al. (2004) values given in acres converted to ha at 1 ha = 2.54 acres, and reported over 10-year period.

Figure 4. Comparison of project-specific and regional approach for estimating baseline and project carbon sequestration (additional to baseline), for 10- and 60-year time horizons, for the Mississippi LYRB case study



Source: derived from Sommer et al., 2004 paper and analysis.

Note: Sommer et al. roadtested WRI/WBCSD project protocol draft guidance for project-specific and performance standard procedures, and used those terms, although a specific standard was not chosen.

TABLE 8:

Testing SRB methods using the

Mississippi afforestation case study

Task I: Estimating the historical stratified baseline emissions rate

SRB Methodology Step	Example: Mississippi Case Study Application
1) Assess data available for stratification of land by characteristics, and then define the baseline accounting region (BAR)	• 4 counties (legal regions within state) in Lower Yazoo River Basin in state of Mississippi, USA
1a) Specify the appropriate metric	• Afforestation rate by county (ha/year)
1b) Specify the C pools and GHGs to be included	• Trees, understory, litter, soil C, forest products; C only
2) Stratify the BAR into relatively homogeneous parcels	• NRI county data used in combination with elevation data to define flooding frequency
3) Define temporal period for estimation of *historical* C emissions rate, by strata	• 1982-97, determined by availability of NRI data on afforestation • Assessed if major break points in trends
4) Establish historical baseline C emissions rate (t C/ha/yr) per strata, using key driver variables.	• NRI data used to quantify afforestation rate for 1982-97. FORCARB model used to estimate C fluxes from afforestation.
Task 2: Establish a Future SRB Emissions Rate	
5) Project future SRB emissions rate	• Afforestation rate is projected for 10 and 60 years, by county, by 3 soil types.
6) Determine a threshold for individual mitigation program eligibility or additionality, if applicable	• Not undertaken in Sommer et al. study. • A threshold could be set using the afforestation and C flux rates in Tables 6 and 7.
6) Review and adjust the SRB emissions rate, at intervals defined by mitigation program guidance	• Not undertaken in Sommer et al. study

Source: Mississippi four-county LYRB case information based on Sommer et al. (2004)